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TECHNICAL NOTE 3291

EXPERIMENTAL INVESTIGATION OF NOTCH-SIZE EFFECTS  
ON ROTATING-BEAM FATIGUE BEHAVIOR  
OF 75S-T6 ALUMINUM ALLOY

By W. S. Hyler, R. A. Lewis, and H. J. Grover

Battelle Memorial Institute



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## EXPERIMENTAL INVESTIGATION OF NOTCH-SIZE EFFECTS

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## SUMMARY

Despite some concern as to proper allowance for the effect of size on the fatigue behavior of materials, little definite information along this line is available for the aluminum alloys of major interest in aircraft design. This investigation was initiated to study the influence of size, particularly the notch-size effect, on extruded 75S-T6 aluminum-alloy test specimens under rotating bending.

Unnotched and notched specimens with minimum-section diameters of 1/8 inch, 1/4 inch, 1/2 inch, 1 inch, and  $1\frac{3}{4}$  inches were tested. For each size, a semicircular groove having a theoretical stress-concentration factor of 2.0 was used. In the largest diameter specimen, a 60° V-notch having a stress-concentration factor of about 19 was tested also.

Preliminary considerations were given to the selection of an appropriate surface finish. The surface finish chosen involved mechanical polishing and a final, light, electrolytic polish.

Within the large (but not exceptional) scatter of fatigue strengths observed, no general size effect could be concluded for either unnotched or notched specimens. One exception was the fact that the sharp notch in the large-diameter specimen did not reduce fatigue strengths as much as might have been predicted in view of its high value of theoretical stress-concentration factor.

## INTRODUCTION

A problem of particular concern in designing structures to resist fatigue failure is that of determining how the results of laboratory fatigue tests on small specimens may be extrapolated to useful design values for large monolithic or built-up structures or components. There

is evidence that large specimens may have significantly lower fatigue strengths than small test specimens of the same material. It also appears that notches in large specimens may be more detrimental than geometrically similar notches in small specimens. However, the literature on the effect of size of specimen on the fatigue behavior of materials is not in complete agreement; hence, specific design rules have been difficult to formulate.

Kuhn and Hardrath (ref. 1) have indicated that the notch-size effect for steels can be predicted reasonably well by using Neuber's concept of a "material constant"  $A$  (called  $p'$  in this report). Moore and Morkovin (refs. 2 and 3) have shown experimental results on steels to be in general agreement with this; however, Moore, Dolan, and Hanley, in notch-size-effect tests on 75S-T aluminum alloys (ref. 4), report an effect of notch radius which differs from this trend for steels. Other aluminum alloys do not appear to have been studied so extensively in this regard. Some investigators (for example, Hempel (ref. 5)) have suggested that surface preparation and other factors can account wholly for apparent size effects in fatigue.

In view of these conflicting observations, this investigation was planned to study possible notch-size effects in rotating-bending fatigue of 75S-T6 aluminum alloy. Several tests were planned to check the results reported in reference 4. These tests involved the use of specimens, both unnotched and notched with geometrically similar grooves, having five different diameters,  $1/8$ ,  $1/4$ ,  $1/2$ ,  $1$ , and  $1\frac{3}{4}$  inches. In addition, it was decided to investigate the effect of a  $60^\circ$  V-notch ("Templin notch"), geometrically scaled to a  $1\frac{3}{4}$ -inch minimum-section diameter; this would afford information concerning the influence of a relatively sharp notch on a large section.

This work was conducted at Battelle Memorial Institute under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

#### MATERIAL AND SPECIMEN DETAILS

The material used in this investigation was 75S-T6 aluminum alloy. It was obtained from the Aluminum Company of America in the form of 3-inch-diameter round bars. Static tests were made on specimens machined from several bars. Specimens were taken from locations corresponding to the outer fibers of fatigue-test specimens. The average mechanical properties were:

Ultimate tensile strength, ksi . . . . .	87.0
Yield strength (0.2 percent), ksi . . . . .	79.2
Reduction of area, percent . . . . .	16.6
Elongation, percent . . . . .	12.2
Modulus of elasticity, psi . . . . .	$10.5 \times 10^6$

Figure 1 shows schematically the location of the minimum test section of each size of specimen with reference to the original 3-inch-diameter bar. As noted, specimens were machined so that critically stressed material was always taken from approximately the same radial distance with reference to the center line of the bar.

Figure 2 shows the dimensions of the specimens tested, and table 1 gives the pertinent dimensions and details of notches. It will be noted that all notches but one were made geometrically similar so as to have a theoretical stress-concentration factor  $K_t$  equal to 2.0. The exception, the sharp Templin notch, had an estimated theoretical stress-concentration factor of 19.2, nearly 10 times as great as that for the other notches.

Figure 3 is a photograph of the same specimens after fatigue failure. This photograph illustrates the appearances of the different-sized test pieces.

Surface preparation of the specimens is described in some detail in a subsequent section.

#### FATIGUE-TESTING MACHINES

Details of the machines used for rotating-beam testing are given in table 2 and illustrated in figures 4 to 8. All machines were equipped with cycle counters and with cut-off devices to stop the machine when failure occurred. Each machine was calibrated prior to testing. It was estimated that the precision of loading was better than 2 percent in every case.

It will be noted that the machines differ in type of loading (that is, cantilever versus uniform moment) and in speed. Previous experience has not shown these differences to be significant in this type of fatigue test.

## SURFACE PREPARATION

Of primary concern was a method of surface preparation that would produce comparable surface finishes in different-sized notched and unnotched specimens.

Several possibilities were considered: (1) the as-machined surface, (2) a mechanically polished surface, and (3) an electro-polished surface. The first two methods of surfacing may produce thin layers of cold-worked material and corresponding residual stresses, and these may differ with specimen size. Electropolishing may cause differential etching and pitting.

Some preliminary experiments were made to check the surface finishes produced by the various methods mentioned. In these experiments, and in later work, mechanical polishing was carried out on the special setup shown in figure 9. As may be noted in this figure, specimens were driven in lathe centers by a small motor. The polishing wheel was driven by another motor. The motor speeds were adjustable so that relative velocities of specimen and wheel (for all sizes of specimen) were of the same order of magnitude. The polishing wheel and associated driving mechanism were mounted on a table which was adjustable in three directions.

Unnotched specimens were polished with a disk-type polishing wheel (one size of wheel for each specimen). The disks were of Masonite, with a layer of sponge rubber cemented on the circumference. Then a layer of felt was wrapped around the rubber. Cutting compound was applied liberally during rotation of the wheel and specimen.

Notched specimens were polished with an appropriate-diameter cord. This cord was laid in the notch and had a small weight attached at the free end. Then the cord was rotated, as was the specimen, with cutting compound liberally applied.

The mechanical-polishing procedure involved the following steps:

(1) After lathe turning, each specimen was mechanically polished using 600-grit emery dust in a liberal supply of cutting oil. About 0.0015 to 0.0025 inch of material on the diameter was removed by this polishing operation.

(2) Each specimen was then mechanically polished with chromium-oxide rouge suspended in kerosene oil. This operation removed about 0.0005 to 0.001 inch of stock on the diameter.

A number of specimens were then electropolished by the removal of 0.0003 to 0.0005 inch from the diameter. During the polishing, frequent checks of diameter and of notch profile were made with a 50:1 shadowgraph.

Figures 10 to 13 show the surface finishes of specimens as lathe turned, after mechanical polishing, and after mechanical polishing plus electrolytic polishing. To a degree greater than is apparent in the photograph, the electrolytic polishing provided a very smooth surface. Although localized pitting was present, the deepest pits examined were about 0.0003 inch deep.

Some tests were made on 1/8-inch-, 1/4-inch-, and  $1\frac{3}{4}$ -inch-diameter notched and unnotched specimens to determine the effect of surface finish on the fatigue behavior of 75S-T6 aluminum alloy. Two load levels were chosen - 30 and 40 ksi for the unnotched specimens and 20 and 30 ksi for the notched specimens. Four 1/8-inch-diameter and four 1/4-inch-diameter specimens were tested at these stress levels, following each step of surface preparation previously outlined. A limited number of  $1\frac{3}{4}$ -inch-diameter specimens were tested also. The results of these tests are presented in tables 3 to 5 and plotted on S-log N coordinate paper in figures 14 to 16.

Some interesting comparisons can be drawn from the results. For example, the unnotched specimens showed an increasing average lifetime and scatter as the surface finish varied from as machined to machined plus first and second mechanical polishes. However, after electropolishing, the average lifetime fell below that of the as-machined specimen, and the scatterband was quite small.

In the case of the notched specimens, all the data fell within a narrow lifetime range. However, data for electropolished specimens were on the low side of this range.

Apparently, even though extreme care was exercised in the machining and mechanical-polishing operations, some surface effects were encountered. Subsequent electropolishing probably removed some disturbed surface material, but the resulting surface was not entirely free of small pits.

In view of the apparent somewhat greater consistency of results (especially for unnotched specimens), as well as the apparently smoother surface after electropolishing, and the expectation that this polishing removed a final layer without imparting cold-work, this finish was adopted for all subsequent tests.

## FATIGUE-TEST RESULTS

The results of fatigue tests on various sizes of specimens having the surface finish described are given in tables 6 to 10 and are plotted on S-N graphs in figures 17 to 22.

In the S-N plots, solid lines representing estimated "mean" values are faired through the data points.

## DISCUSSION OF RESULTS

Table 11 lists the values of fatigue strength (from the S-N curves in figs. 17 to 22) at  $10^7$  cycles. Each value is accompanied by a "precision number," estimated in view of the scatter of data points about the corresponding S-N curve. These estimated precision values, admittedly, are arbitrary but they will serve to focus attention, in the following discussion, upon the necessity of consideration of scatter in attempting to draw conclusions.

Figure 23 shows the results of table 11 in a plot of fatigue strength versus specimen diameter. Experimental values are indicated as vertical lines representing the estimated scatter; the solid-line curves are drawn through the estimated mean values. Whereas speculations as to a "size effect" might be based on the lines through the mean values, it appears, in view of the scatter, that such speculations might be invalid.

Figure 23 also presents the results of a previous investigation (ref. 4) by dashed lines through circular data "points." The results of the previous investigation suggested that unnotched fatigue strength might decrease with increasing specimen diameter, but this trend is not confirmed by present results. However, caution is needed in considering apparent disagreements in the results of the two investigations for the following reasons: There were differences in surface preparation, and scatter in test results existed in each case.

Table 12 shows the values of fatigue-notch factor  $K_f$  and of fatigue-notch-sensitivity index  $q$  derived from the fatigue-strength values in table 11. Extreme as well as mean values are listed in order to indicate the observed scatter of test results. Conclusions concerning the variation of  $K_f$  with specimen diameter or with notch radius appear speculative, in view of the extreme values representing scatter in test results.

One result, however, appears to have some significance: The sharply notched large-diameter specimen exhibited a relatively low value of notch-sensitivity index  $q$ . Figure 24 illustrates this graphically. In this figure, the heavy vertical lines represent extreme limits of observed values. The dashed curve represents the values of

$$q = (K_n - 1)/(K_t - 1)$$

where

$K_n$       Neuber's stress-concentration factor,  $1 + (K_t - 1)/(1 + \sqrt{\rho'/r})$   
             (ref. 6)

and where

$r$           notch radius

$\rho'$         Neuber's material constant

The value of  $\rho'$  used in this illustration is 0.007 inch, which provides fair agreement with the observed data. It appears that the experimental results are not incompatible with a curve of  $q$  versus  $\rho'$  of the general type suggested by Neuber. On the other hand, it also appears that the results are not sufficiently accurate to indicate the shape of such a curve.

Finally, additional study will be necessary to discover possible size effects and notch-size effects on fatigue behavior of aluminum alloys. From this investigation it appears that scatter in observed fatigue strengths of unnotched specimens presents the outstanding difficulty. This has been shown here primarily for electropolished 75S-T6 extrusions; however, there were indications of at least as much scatter in data obtained with specimens of this material with other surface finishes. Other experiments (note, for example, ref. 7) have suggested particular variability in fatigue-test results for this alloy; however, there is considerable evidence that many materials show scatter in fatigue properties. Further work should devote considerable emphasis to (1) study of surface finish and (2) statistical evaluation of results.

#### CONCLUDING REMARKS

Rotating-bending tests on specimens of 75S-T6 aluminum alloy showed considerable influence of surface finishing upon fatigue strength. On the basis of preliminary considerations, a finishing procedure consisting of mechanical polishing followed by electrolytic removal of a thin layer was adopted for subsequent tests.



Tests on unnotched and notched specimens of minimum diameters from 1/8 inch to  $1\frac{3}{4}$  inches did not show systematic evidence of size effect or of notch-size effect. This conclusion is limited in significance by the scatter of test results, particularly for unnotched specimens.

One result appeared significant beyond the limitation of scatter: namely, a small-radius notch in a large-diameter specimen produced a relatively small fatigue-strength reduction ( $K_f$  about 1.8), in view of its large theoretical stress-concentration factor ( $K_t$  about 19).

The results of this investigation show that further work will be needed to understand fully the possible effects of specimen size and notch size upon the fatigue strengths of aluminum alloys. Observations from the present study suggest some specific precautions in further work along this line.

Battelle Memorial Institute,  
Columbus, Ohio, November 13, 1953.

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TABLE 1.- NOTCH DETAILS OF SPECIMENS FOR SIZE-EFFECT TESTS

Notch form	Minimum diameter, d, in.	Maximum diameter, D, in.	Notch radius, r, in.	Flank angle, $\omega$ , radians	$K_t$
Semicircular groove	0.125	0.145	0.010	0	2.0
	.250	.290	.020	0	2.0
	.500	.580	.040	0	2.0
	1.000	1.160	.080	0	2.0
	1.750	2.030	.140	0	2.0
60° V groove	1.750	2.545	.001	$\pi/3$	19.2

TABLE 2.- DETAILS OF ROTATING-BEAM FATIGUE-TEST MACHINES

Specimen diameter, in.	Machine	Type	Capacity, in-lb	Operating speed, cpm
1/8	Krouse	Cantilever	16	10,000
1/4	R. R. Moore	Four-point loading	100	10,000
1/2	Battelle	Cantilever	1,500	1,200
1	Baldwin-Southwark	Four-point loading	10,000	3,000
1 3/4	Krouse	Cantilever	60,000	1,200

TABLE 3.- RESULTS OF FATIGUE TESTS ON 1/8-INCH-DIAMETER SPECIMENS  
AT DIFFERENT STAGES OF SURFACE-FINISH PREPARATION

[The first and second polishes were mechanical and the third polish was electrolytic]

Stage of surface preparation	Stress, ksi	Cycles of reversed bending for fracture
Unnotched specimens		
First and second polishes	40.0	147,000
	40.0	285,000
	40.0	400,000
	40.0	460,000
First, second, and third polishes	40.0	83,000
	40.0	85,000
	40.0	86,000
	40.0	88,000
As machined	30.0	1,434,000
	30.0	5,961,000
	30.0	6,721,000
	30.0	21,138,000
First polish	30.0	8,132,000
	30.0	15,084,000
	30.0	17,081,000
	30.0	21,404,000
First and second polishes	30.0	1,467,000
	30.0	5,501,000
	30.0	6,776,000
	30.0	29,893,000
First, second, and third polishes	30.0	130,000
	30.0	135,000
	30.0	137,000
	30.0	440,000

TABLE 3.- RESULTS OF FATIGUE TESTS ON 1/8-INCH-DIAMETER SPECIMENS

AT DIFFERENT STAGES OF SURFACE-FINISH PREPARATION - Concluded

[The first and second polishes were mechanical and the third polish was electrolytic]

Stage of surface preparation	Stress, ksi	Cycles of reversed bending for fracture
Notched specimens ( $K_t = 2.0$ )		
First and second polishes	30.0	57,000
	30.0	71,000
	30.0	76,000
	30.0	77,000
First, second, and third polishes	30.0	62,000
	30.0	64,000
	30.0	71,000
	30.0	73,000
As machined	20.0	242,000
	20.0	427,000
	20.0	860,000
	20.0	1,835,000
First polish	20.0	318,000
	20.0	1,455,000
	20.0	1,500,000
	20.0	1,973,000
First and second polishes	20.0	495,000
	20.0	583,000
	20.0	656,000
	20.0	843,000
First, second, and third polishes	20.0	160,000
	20.0	190,000
	20.0	358,000
	20.0	358,000

TABLE 4.- RESULTS OF FATIGUE TESTS ON 1/4-INCH-DIAMETER SPECIMENS

AT DIFFERENT STAGES OF SURFACE-FINISH PREPARATION

[The first and second polishes were mechanical and the third polish was electrolytic]

Stage of surface preparation	Stress, ksi	Cycles of reversed bending for fracture
Unnotched specimens		
First and second polishes	40.0	235,000
	40.0	349,000
	40.0	368,000
	40.0	394,000
First, second, and third polishes	40.0	70,000
	40.0	79,000
	40.0	81,000
	40.0	88,000
As machined	30.0	466,000
	30.0	549,000
	30.0	728,000
	30.0	1,767,000
First polish	30.0	2,040,000
	30.0	4,657,000
	30.0	6,330,000
	30.0	9,122,000
First and second polishes	30.0	1,807,000
	30.0	2,696,000
	30.0	8,114,000
	30.0	18,765,000
First, second, and third polishes	30.0	296,000
	30.0	320,000
	30.0	349,000
	30.0	362,000

TABLE 4.- RESULTS OF FATIGUE TESTS ON 1/4-INCH-DIAMETER SPECIMENS

AT DIFFERENT STAGES OF SURFACE-FINISH PREPARATION - Concluded

[The first and second polishes were mechanical and the third polish was electrolytic]

Stage of surface preparation	Stress, ksi	Cycles of reversed bending for fracture
Notched specimens ( $K_t = 2.0$ )		
First and second polishes	30.0	22,000
	30.0	24,000
	30.0	28,000
	30.0	30,000
First, second, and third polishes	30.0	26,000
	30.0	28,000
	30.0	30,000
	30.0	31,000
As machined	20.0	444,000
	20.0	446,000
	20.0	479,000
	20.0	494,000
First polish	20.0	403,000
	20.0	404,000
	20.0	414,000
	20.0	588,000
First and second polishes	20.0	261,000
	20.0	291,000
	20.0	366,000
	20.0	442,000
First, second, and third polishes	20.0	282,000
	20.0	304,000
	20.0	319,000
	20.0	321,000



TABLE 5.- RESULTS OF FATIGUE TESTS ON  $1\frac{3}{4}$ -INCH-DIAMETER  
SPECIMENS AT DIFFERENT STAGES OF SURFACE-FINISH PREPARATION  
[First and second polishes were mechanical]

Stage of surface preparation	Stress, ksi	Cycles of reversed bending for fracture
Unnotched specimens		
As machined	30.0	4,008,000
First and second polishes, plus two times normal electropolish	30.0	323,000
Notched specimen ( $K_t = 2.0$ )		
First and second polishes, plus two times normal electropolish	18.0	1,060,000

TABLE 6.- RESULTS OF FATIGUE TESTS ON 1/8-INCH-DIAMETER SPECIMENS

Stress, ksi	Cycles of reversed bending for fracture	Remarks
Unnotched specimens		
50.0	30,000	
50.0	45,000	
40.0	83,000	
40.0	85,000	
40.0	86,000	
40.0	88,000	
40.0	257,000	
35.0	115,000	
35.0	147,000	
30.0	130,000	
30.0	135,000	
30.0	137,000	
30.0	440,000	
30.0	1,125,000	
30.0	8,932,000	
27.5	519,000	
27.5	880,000	
26.0	447,000	
26.0	5,949,000	
25.0	687,000	
25.0	768,000	
24.0	859,000	
24.0	956,000	
24.0	2,886,000	
24.0	9,080,000	
23.0	4,084,000	
23.0	14,396,000	
22.0	4,456,000	
22.0	7,048,000	
22.0	20,032,000	Did not fail
22.0	26,350,000	Did not fail
22.0	30,585,000	Did not fail

TABLE 6.- RESULTS OF FATIGUE TESTS ON 1/8-INCH-DIAMETER

SPECIMENS - Concluded

Stress, ksi	Cycles of reversed bending for fracture	Remarks
Notched specimens ( $K_t = 2.0$ )		
40.0	14,000	
40.0	16,000	
35.0	21,000	
35.0	27,000	
30.0	62,000	
30.0	64,000	
30.0	71,000	
30.0	73,000	
30.0	89,000	
25.0	57,000	
25.0	168,000	
25.0	230,000	
25.0	252,000	
20.0	160,000	
20.0	190,000	
20.0	358,000	
20.0	358,000	
20.0	484,000	
18.0	2,378,000	
17.5	599,000	
17.5	1,990,000	
16.0	1,516,000	
16.0	1,709,000	
15.0	478,000	
15.0	700,000	
15.0	1,167,000	
15.0	1,645,000	
15.0	17,760,000	
15.0	21,140,000	Did not fail
15.0	44,278,000	Did not fail
14.0	27,375,000	Did not fail
14.0	55,000,000	Did not fail
14.0	57,627,000	Did not fail
12.5	1,133,000	
12.5	56,057,000	Did not fail

TABLE 7.- RESULTS OF FATIGUE TESTS ON 1/4-INCH-DIAMETER SPECIMENS

Stress, ksi	Cycles of reversed bending for fracture	Remarks
Unnotched specimens		
45.0	52,000	
40.0	70,000	
40.0	79,000	
40.0	81,000	
40.0	88,000	
40.0	95,000	
35.0	140,000	
30.0	296,000	
30.0	320,000	
30.0	349,000	
30.0	362,000	
30.0	417,000	
28.0	445,000	
28.0	510,000	
26.0	1,093,000	
26.0	4,337,000	
26.0	9,775,000	
26.0	12,800,000	
26.0	22,113,000	
25.0	1,783,000	
25.0	3,442,000	
25.0	10,825,000	
25.0	43,000,000	Did not fail
23.0	20,424,000	
23.0	42,125,000	Did not fail
23.0	50,000,000	Did not fail
23.0	59,268,000	Did not fail
23.0	69,790,000	Did not fail

TABLE 7.- RESULTS OF FATIGUE TESTS ON 1/4-INCH-DIAMETER  
SPECIMENS - Concluded

Stress, ksi	Cycles of reversed bending for fracture  Notched specimens ( $K_t = 2.0$ )	Remarks
35.0	17,000	
30.0	26,000	
30.0	28,000	
30.0	29,000	
30.0	30,000	
30.0	31,000	
30.0	44,000	
25.0	78,000	
25.0	127,000	
20.0	270,000	
20.0	282,000	
20.0	298,000	
20.0	304,000	
20.0	319,000	
20.0	321,000	
15.0	690,000	
15.0	1,340,000	
12.5	2,590,000	
12.5	2,610,000	
12.0	2,950,000	
12.0	14,680,000	
11.0	27,905,000	Did not fail
11.0	32,115,000	Did not fail
11.0	57,548,000	Did not fail

TABLE 8.- RESULTS OF FATIGUE TESTS ON 1/2-INCH-DIAMETER SPECIMENS

Stress, ksi	Cycles of reversed bending for fracture	Remarks
Unnotched specimens		
50.0	22,000	
40.0	58,000	
30.0	223,000	
24.0	536,000	
24.0	1,074,000	
24.0	8,200,000	
23.0	556,000	
23.0	743,000	
23.0	1,074,000	
23.0	1,591,000	
23.0	9,958,000	
22.0	20,005,000	
22.0	20,078,000	Did not fail
22.0	22,000,000	Did not fail
Notched specimens ( $K_t = 2.0$ )		
30.0	21,000	
25.0	35,000	
20.0	109,000	
15.0	306,000	
12.5	924,000	
12.5	5,335,000	
11.0	2,335,000	
11.0	2,703,000	
11.0	3,227,000	
11.0	9,236,000	
10.0	5,218,000	
10.0	20,900,000	Did not fail
10.0	24,500,000	Did not fail
9.0	22,507,000	Did not fail

TABLE 9.- RESULTS OF FATIGUE TESTS ON 1-INCH-DIAMETER SPECIMENS

Stress, ksi	Cycles of reversed bending for fracture	Remarks
Unnotched specimens		
50.0	65,000	Did not fail
45.0	81,000	
40.0	187,000	
35.0	164,000	
35.0	192,000	
30.0	780,000	
30.0	6,099,000	
27.5	611,800	
27.5	2,316,600	
26.0	6,628,500	
26.0	8,710,000	
25.0	3,082,200	
25.0	20,950,000	
24.0	5,205,000	
24.0	23,069,000	
23.0	21,816,000	Did not fail
23.0	31,135,000	Did not fail
Notched specimens ( $K_t = 2.0$ )		
30.0	49,400	Did not fail
30.0	42,400	
25.0	170,000	
21.0	272,000	
20.0	980,000	
18.0	1,292,000	
17.0	1,373,000	
17.0	3,200,000	
16.0	2,044,000	
15.0	10,726,000	
15.0	14,493,000	
15.0	26,480,000	
14.5	4,512,700	
14.0	29,590,000	Did not fail

TABLE 10.- RESULTS OF FATIGUE TESTS ON  $1\frac{3}{4}$ -INCH-DIAMETER SPECIMENS

Stress, ksi	Cycles of reversed bending for fracture	Remarks
Unnotched specimens		
40.0	92,800	
32.5	329,000	
30.0	3,104,400	
30.0	3,611,000	
29.0	749,200	
28.0	960,000	
27.5	3,923,400	
27.0	8,399,600	
27.0	9,737,000	
26.0	6,600,000	
Notched specimens ( $K_t = 2.0$ )		
30.0	32,800	Did not fail
25.0	199,300	
22.0	363,000	
19.0	729,300	
19.0	1,363,000	
18.0	348,400	
18.0	1,412,200	
18.0	1,461,200	
18.0	6,953,000	
16.0	27,000,000	
Notched specimens ( $K_t = 19.2$ )		
25.0	134,400	Rerun of specimen previously tested at 10 ksi
21.0	208,600	
18.0	1,129,000	
18.0	1,352,500	Did not fail
16.0	1,439,800	
16.0	3,582,800	
14.0	27,541,000	
10.0	10,192,000	Did not fail



TABLE 11.- SUMMARY OF FATIGUE STRENGTHS AT  $10^7$  CYCLES

Specimen diameter, in.	Fatigue strength, ksi (a)	
	Unnotched	Notched
1/8	23.0 $\pm$ 2	15.0 $\pm$ 2
1/4	25.0 $\pm$ 2	12.0 $\pm$ 1
1/2	23.0 $\pm$ 1	11.0 $\pm$ 1
1	25.0 $\pm$ 3	15.0 $\pm$ 1
$1\frac{3}{4}$	27.0 $\pm$ 2	17.0 $\pm$ 1
$1\frac{3}{4}$ (60° V)	27.0 $\pm$ 2	15.0 $\pm$ 1

<sup>a</sup>Values were taken from the S-N curves in figures 17 to 22. Precision numbers were estimated arbitrarily in view of the apparent scatter of points.

TABLE 12.- VALUES OF FATIGUE-NOTCH FACTOR AND FATIGUE-NOTCH-SENSITIVITY INDEX

Specimen diameter, in.	Notch radius, r, in.	$K_t$	Fatigue notch factor, $K_f$ , at $10^7$ cycles (a)		Fatigue-notch-sensitivity index, q, at $10^7$ cycles (a)	
			Mean	Extreme	Mean	Extreme
1/8	0.010	2.0	1.5	1.2 1.9	0.5	0.2 .9
1/4	.020	2.0	2.1	1.8 2.5	1.1	.8 1.5
1/2	.040	2.0	2.1	1.8 2.4	1.1	.8 1.4
1	.080	2.0	1.7	1.4 2.0	.7	1.4 1.0
1 3/4	.140	2.0	1.6	1.4 1.8	.6	.4 .8
1 3/4	.001	19.2	1.8	1.6 2.1	.04	.03 .06

<sup>a</sup>The mean and extreme values were calculated from values listed in table 11;  
 $K_f$  = unnotched fatigue strength/notched fatigue strength;  $q = (K_f - 1)/(K_t - 1)$ .

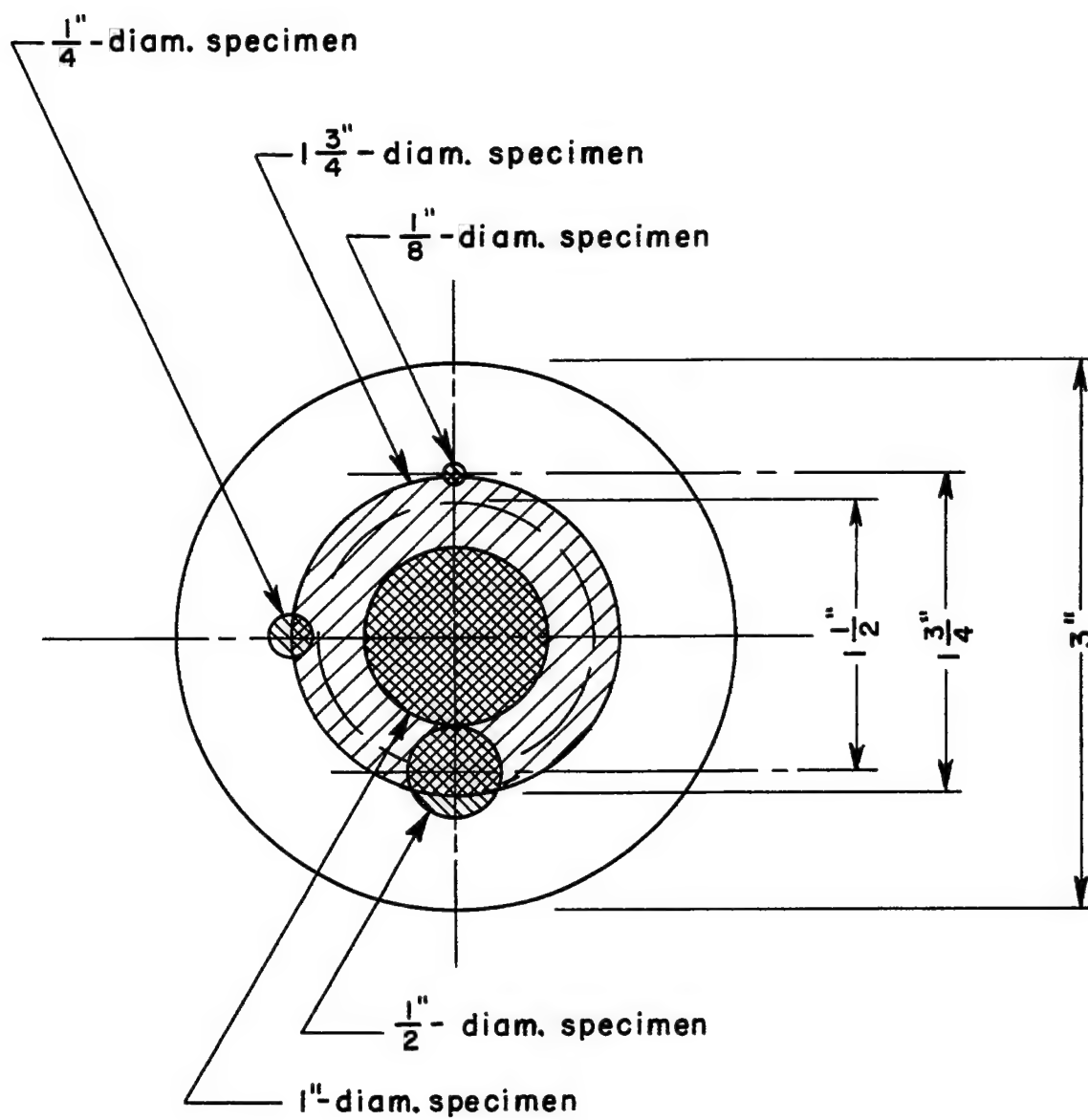
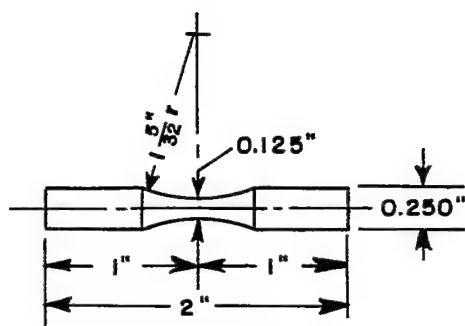
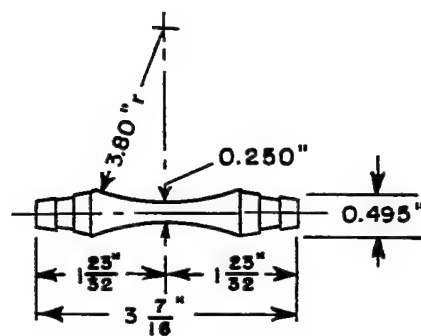


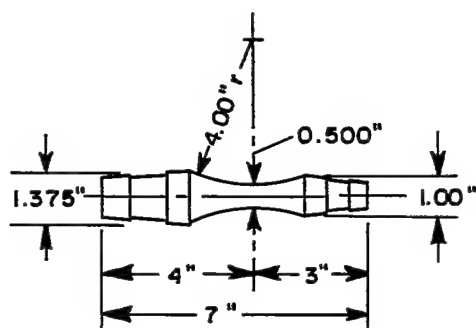
Figure 1.- Location of fatigue specimens in 3-inch-diameter round bar.



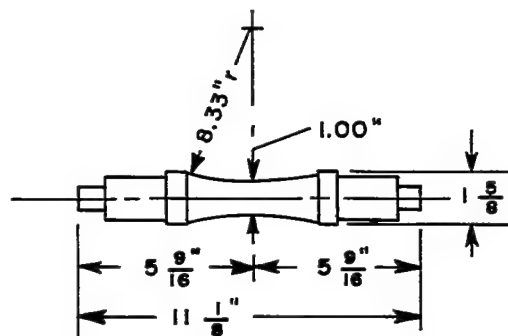
(a)  $\frac{1}{8}$ -inch-diameter unnotched specimen.



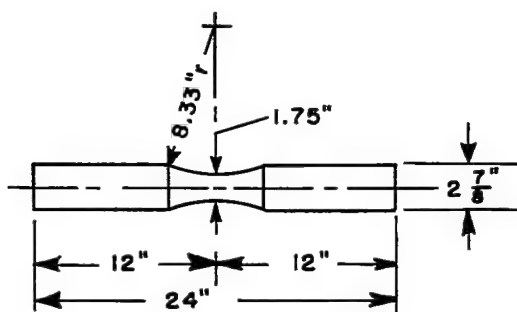
(b)  $\frac{1}{4}$ -inch-diameter unnotched specimen.



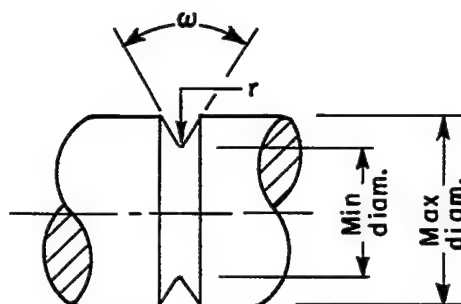
(c)  $\frac{1}{2}$ -inch-diameter unnotched specimen.



(d) 1-inch-diameter unnotched specimen.

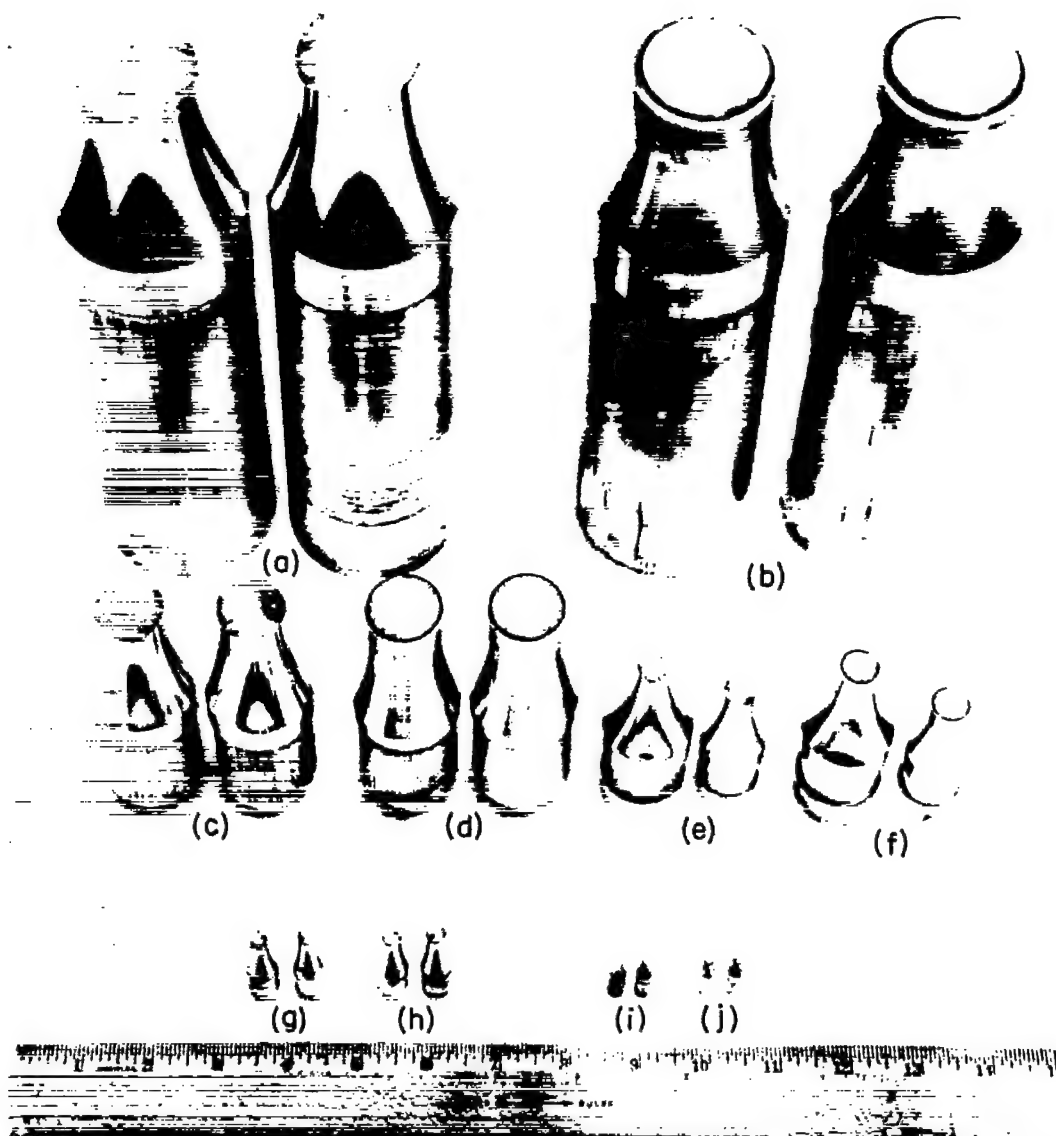


(e)  $\frac{3}{4}$ -inch-diameter unnotched specimen.



(f) Notch configuration. (See table 1 for dimensions.)

Figure 2.- Details of fatigue-test specimens.



(a)  $1\frac{3}{4}$  inches, unnotched.

(b)  $1\frac{3}{4}$  inches, notched.

(c) 1 inch, unnotched.

(d) 1 inch, notched.

(e)  $\frac{1}{2}$  inch, unnotched.

L-85639  
(f)  $\frac{1}{2}$  inch, notched.

(g)  $\frac{1}{4}$  inch, unnotched.

(h)  $\frac{1}{4}$  inch, notched.

(i)  $\frac{1}{8}$  inch, unnotched.

(j)  $\frac{1}{8}$  inch, notched.

Figure 3.- Failed fatigue specimens.

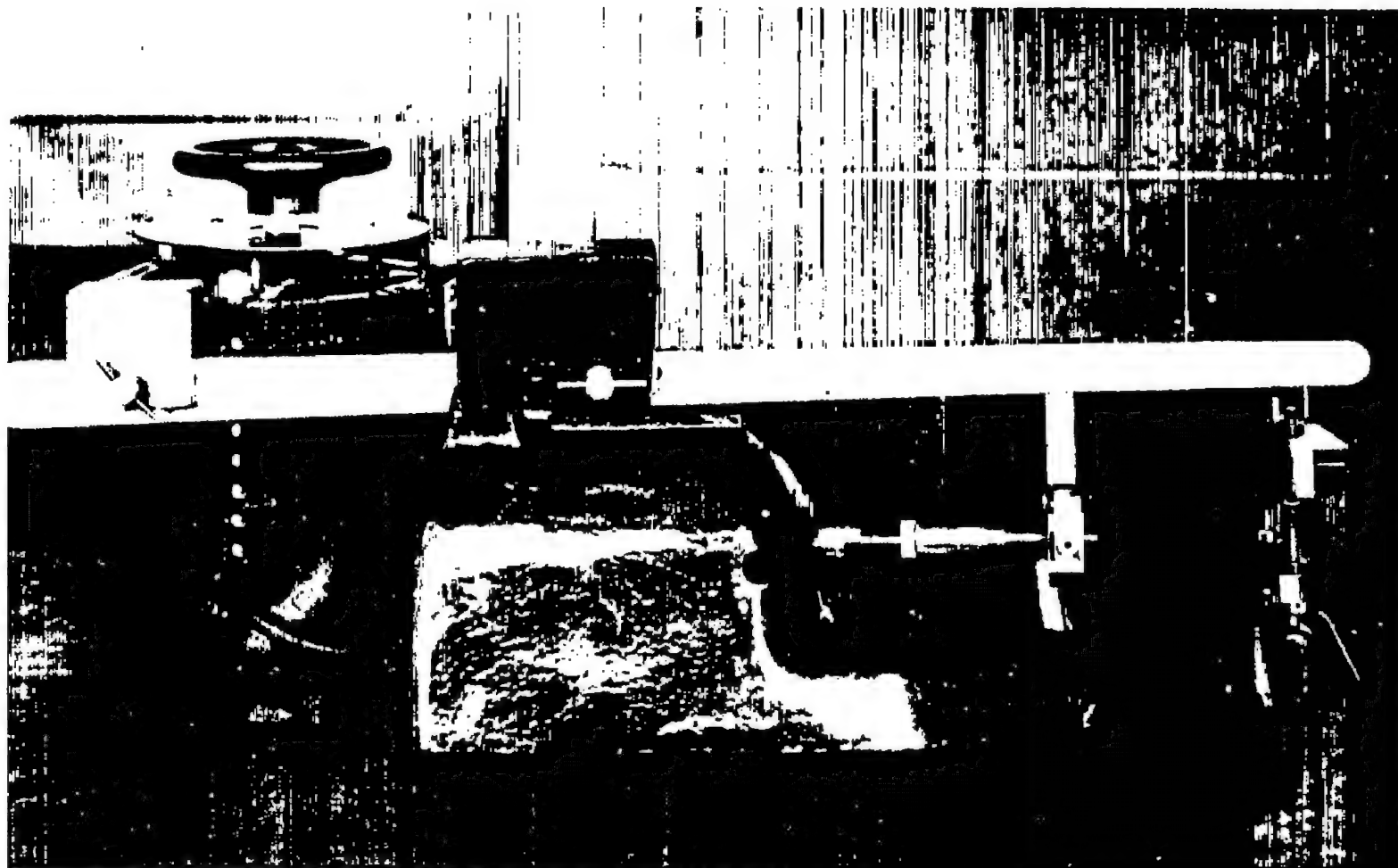


Figure 4.- Krouse fatigue-testing machine used for testing 1/8-inch-diameter  
specimen. L-85640

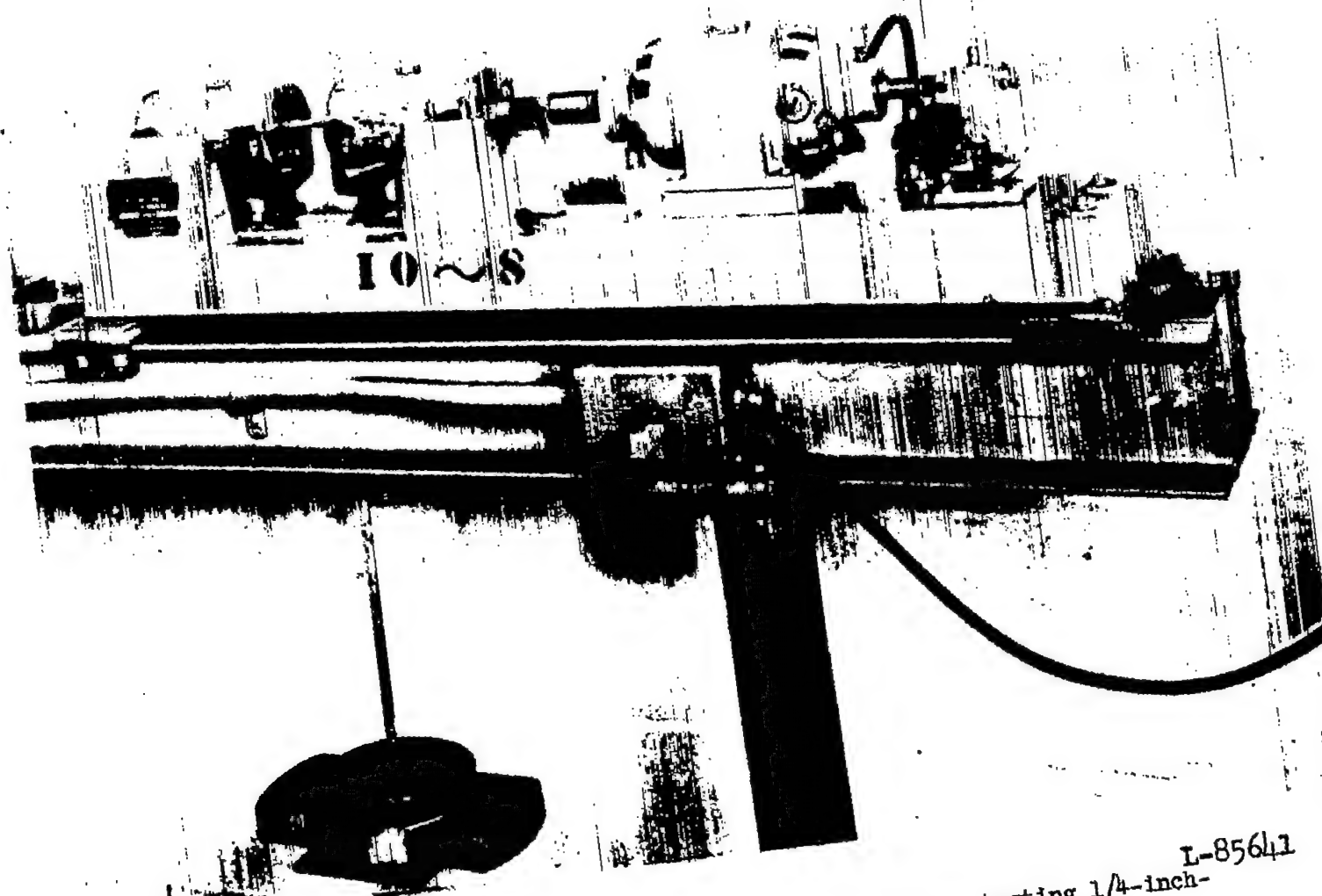


Figure 5.- R. R. Moore fatigue-testing machine used for testing 1/4-inch-diameter specimen. L-85641

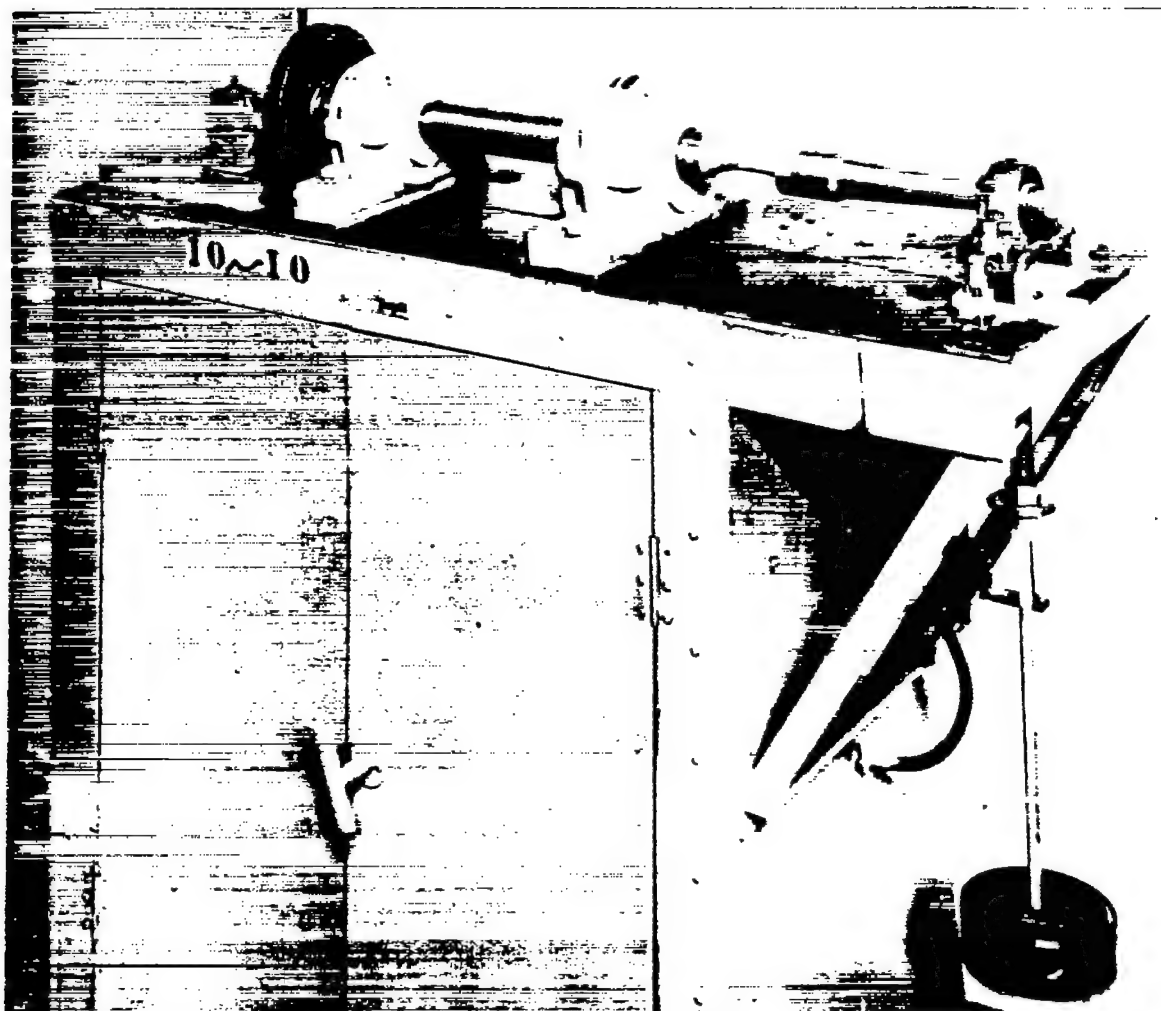


Figure 6.- Battelle fatigue-testing machine used for testing  $1/2$ -inch-diameter specimen. L-85642



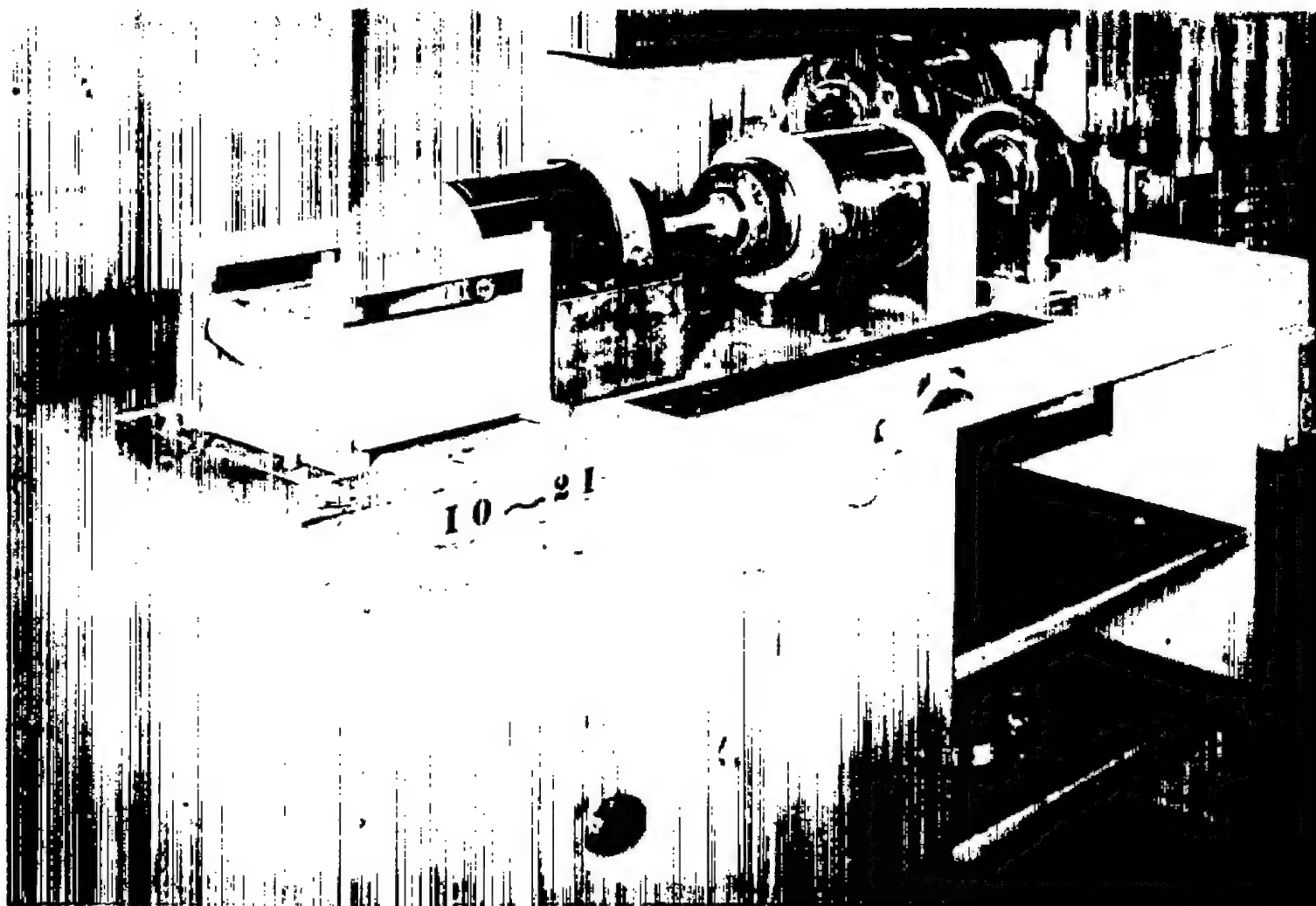


Figure 7.- Baldwin-Southwark fatigue-testing machine used for testing  
1-inch-diameter specimen. L-85643

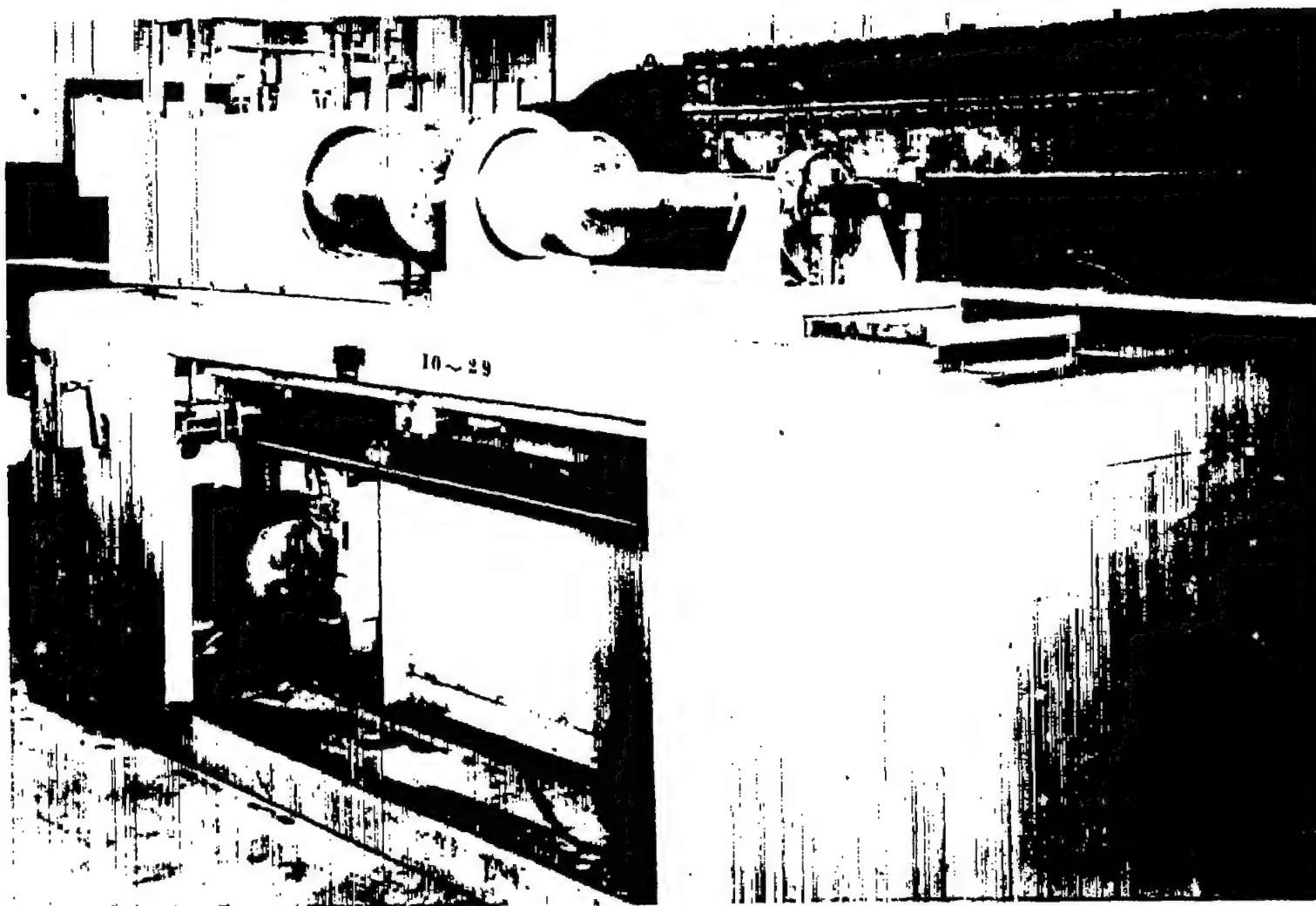
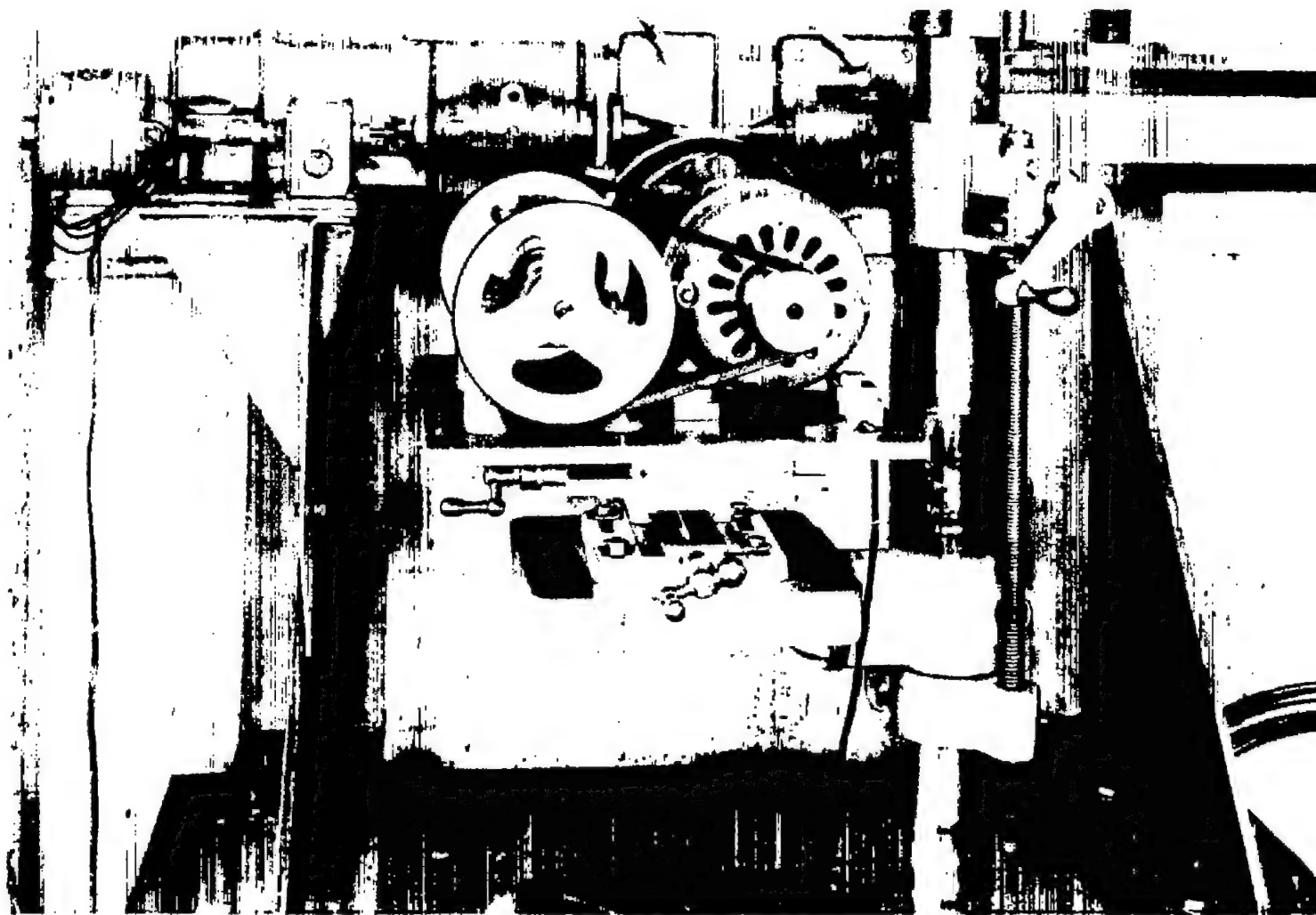
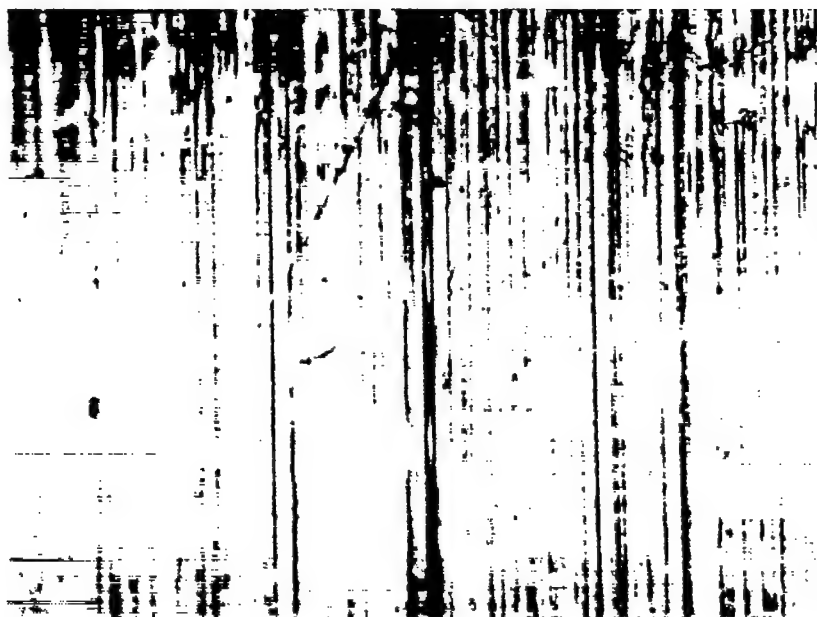


Figure 8.- Krouse fatigue-testing machine used for testing  $1\frac{3}{4}$ -inch-<sup>L-85644</sup>  
diameter specimen.



L-85645  
Figure 9.- Specimen-polishing machine, showing a 1/4-inch-diameter unnotched specimen in position.



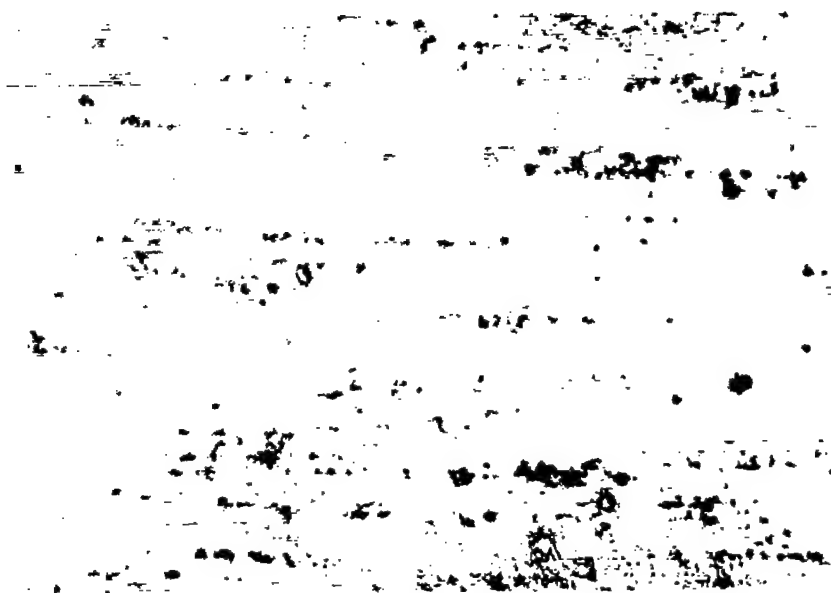
L-85646

Figure 10.- Photomicrograph of the surface-finish condition of a lathe-turned specimen. The machine scratches run circumferentially around the specimen.



L-85647

Figure 11.- Photomicrograph of the surface-finish condition of a mechanically polished specimen. The polishing scratches run longitudinally on the specimen.



L-85648

Figure 12.- Photomicrograph of the surface-finish condition of an electro-polished specimen. The pitting pattern runs longitudinally on the specimen.



L-85649

Figure 13.- Photomicrograph of a transverse section through an electro-polished specimen. Two pits are shown at surface of metal.

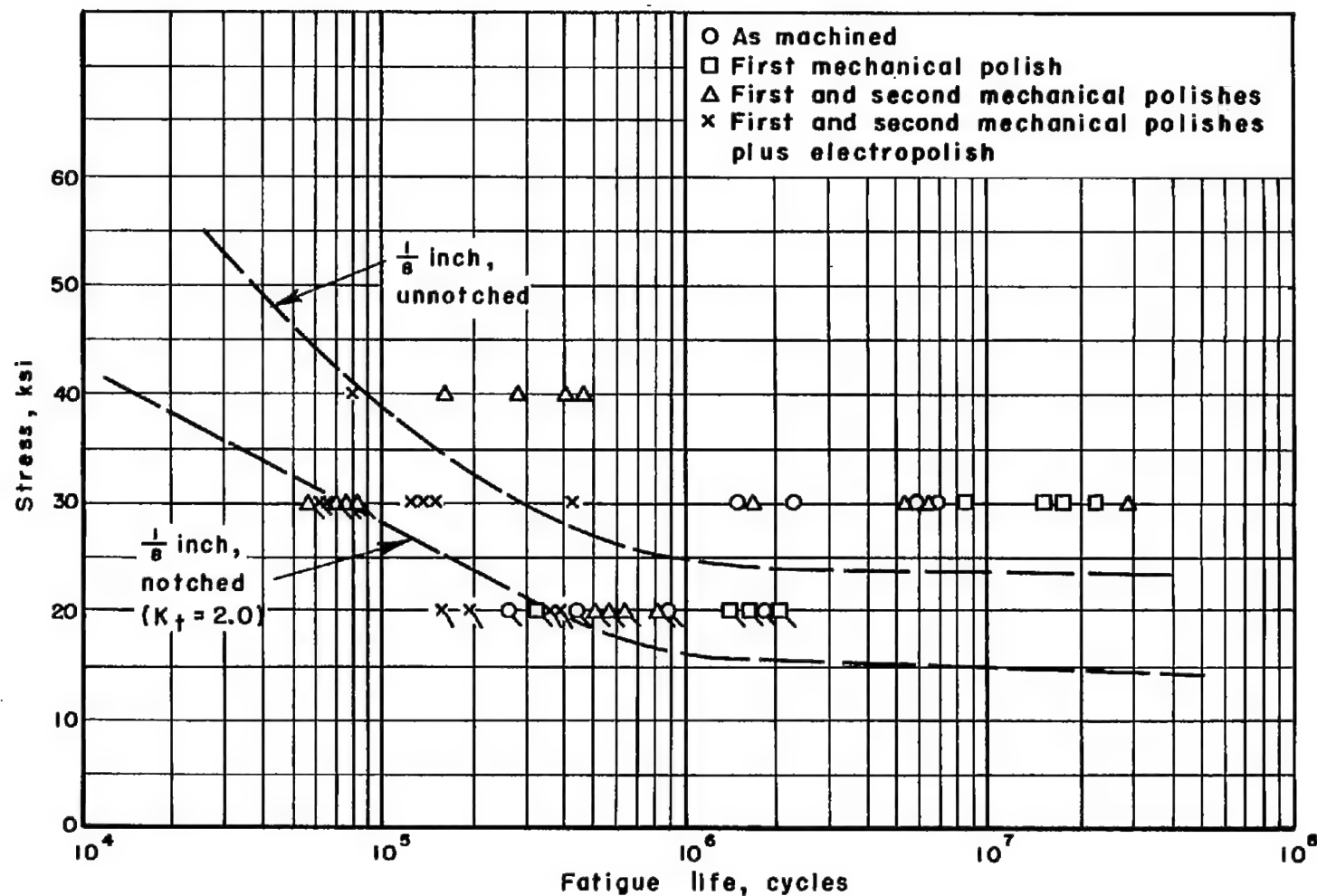


Figure 14.- Surface-polish effect on fatigue life of  $\frac{1}{8}$ -inch-diameter specimens. Unnotched specimens tested at 30 and 40 ksi; notched specimens tested at 20 and 30 ksi. Flags denote notched specimens.

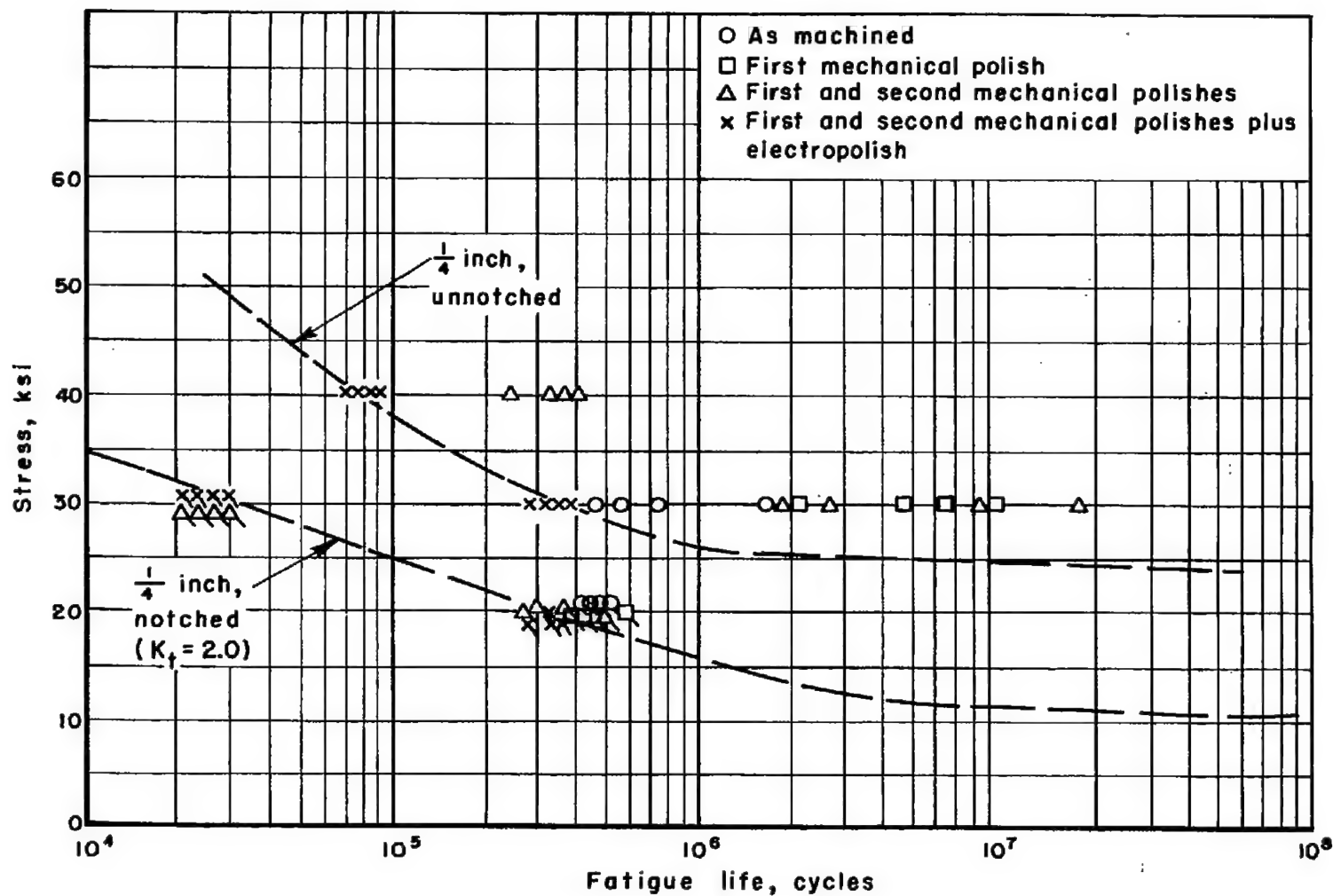


Figure 15.- Surface-polish effects on fatigue life of 1/4-inch-diameter specimens. Unnotched specimen tested at 30 and 40 ksi; notched specimens tested at 20 and 30 ksi. Flags denote notched specimens.

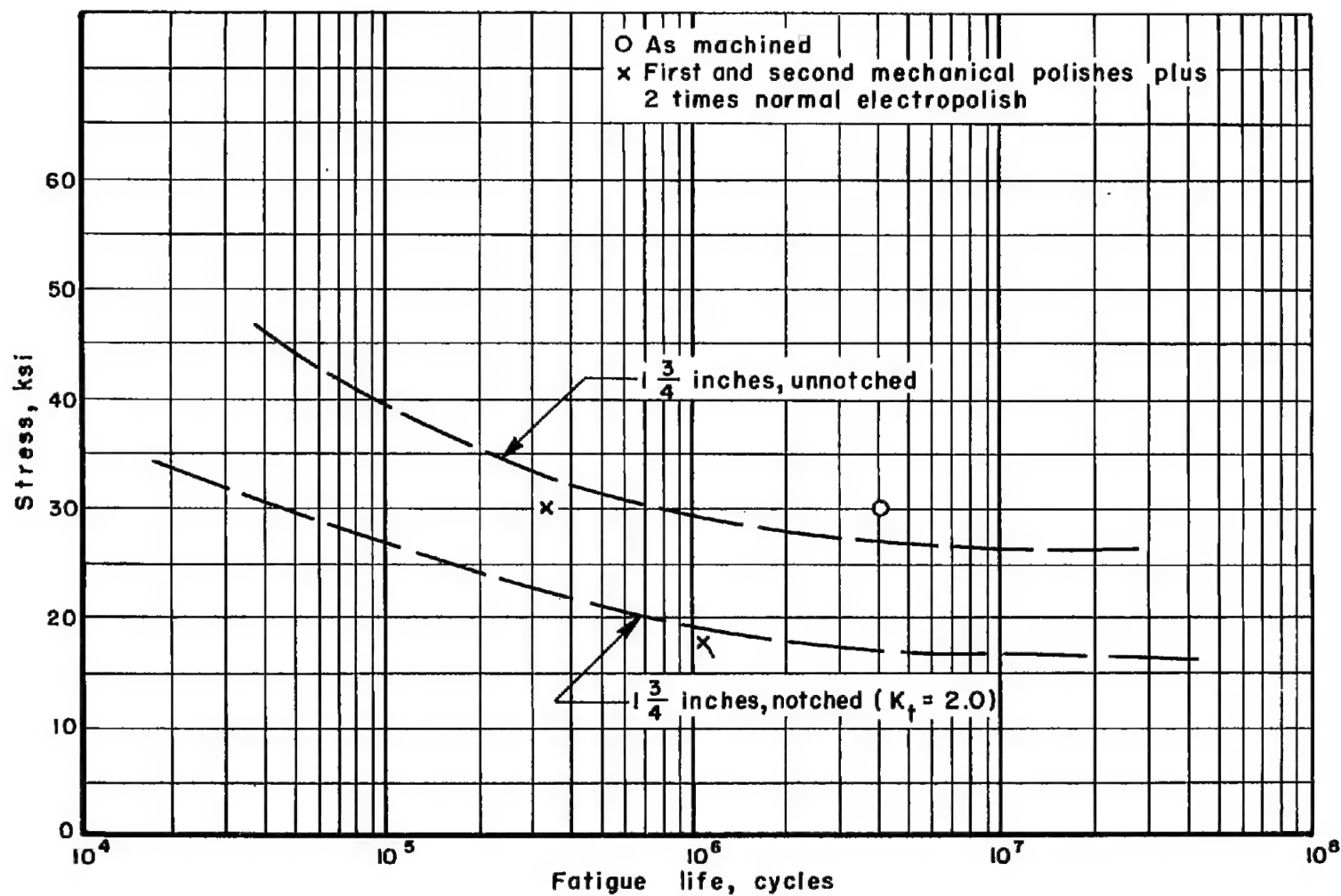


Figure 16.- Surface-polish effect on fatigue life of  $1\frac{3}{4}$ -inch-diameter specimens. Flag denotes notched specimen.



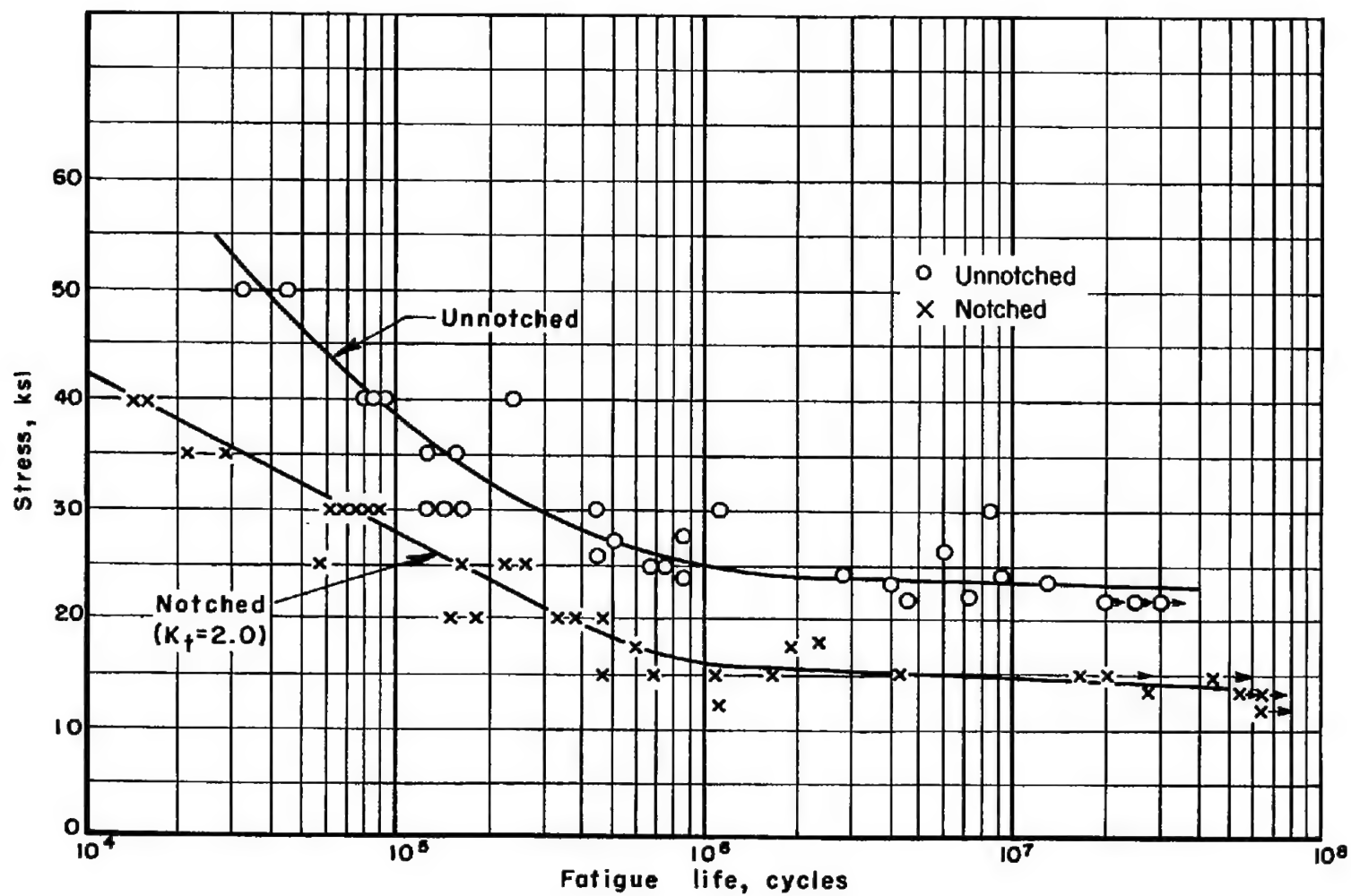


Figure 17.- Fatigue-test results on 1/8-inch-diameter specimens.

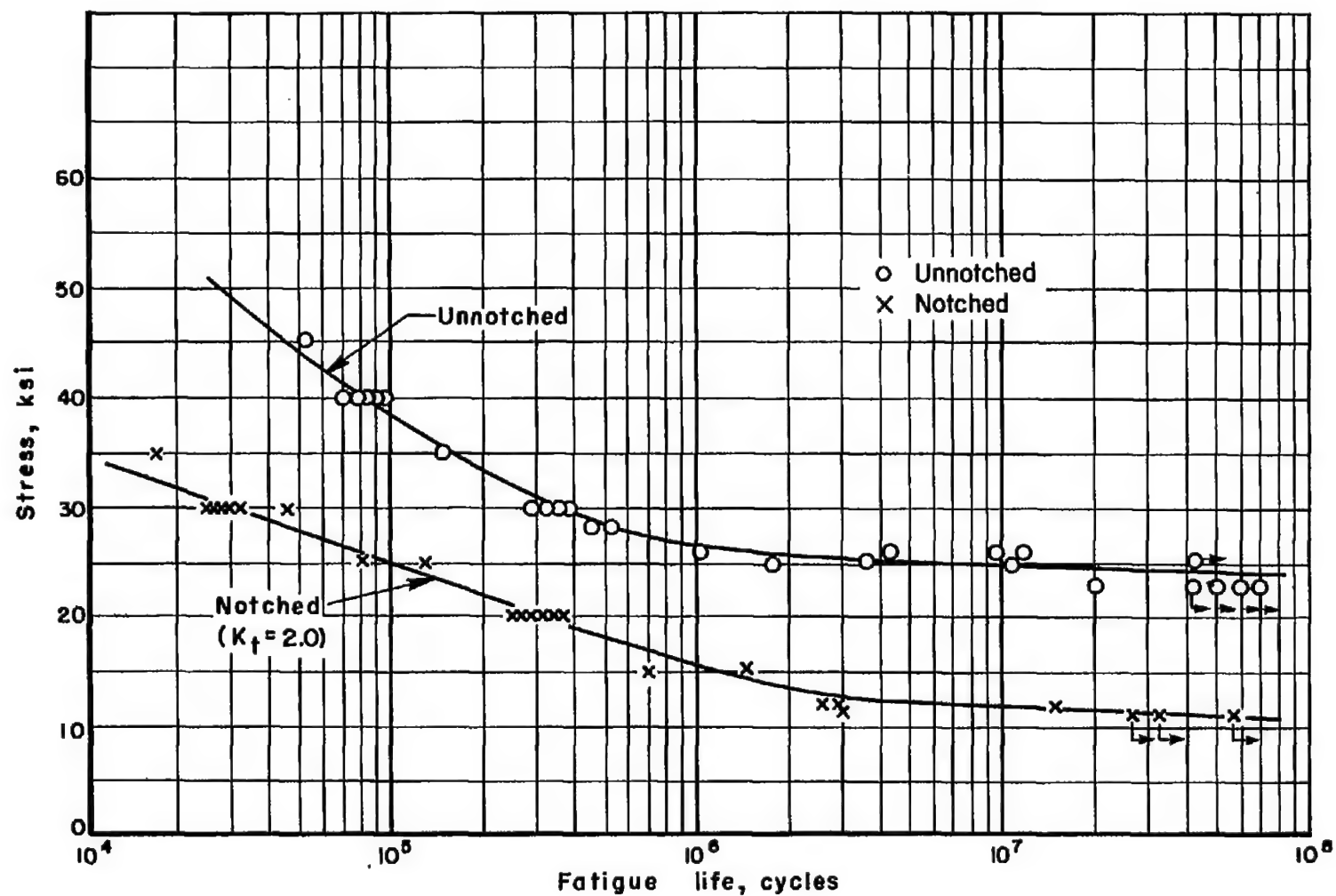


Figure 18.- Fatigue-test results on 1/4-inch-diameter specimens.

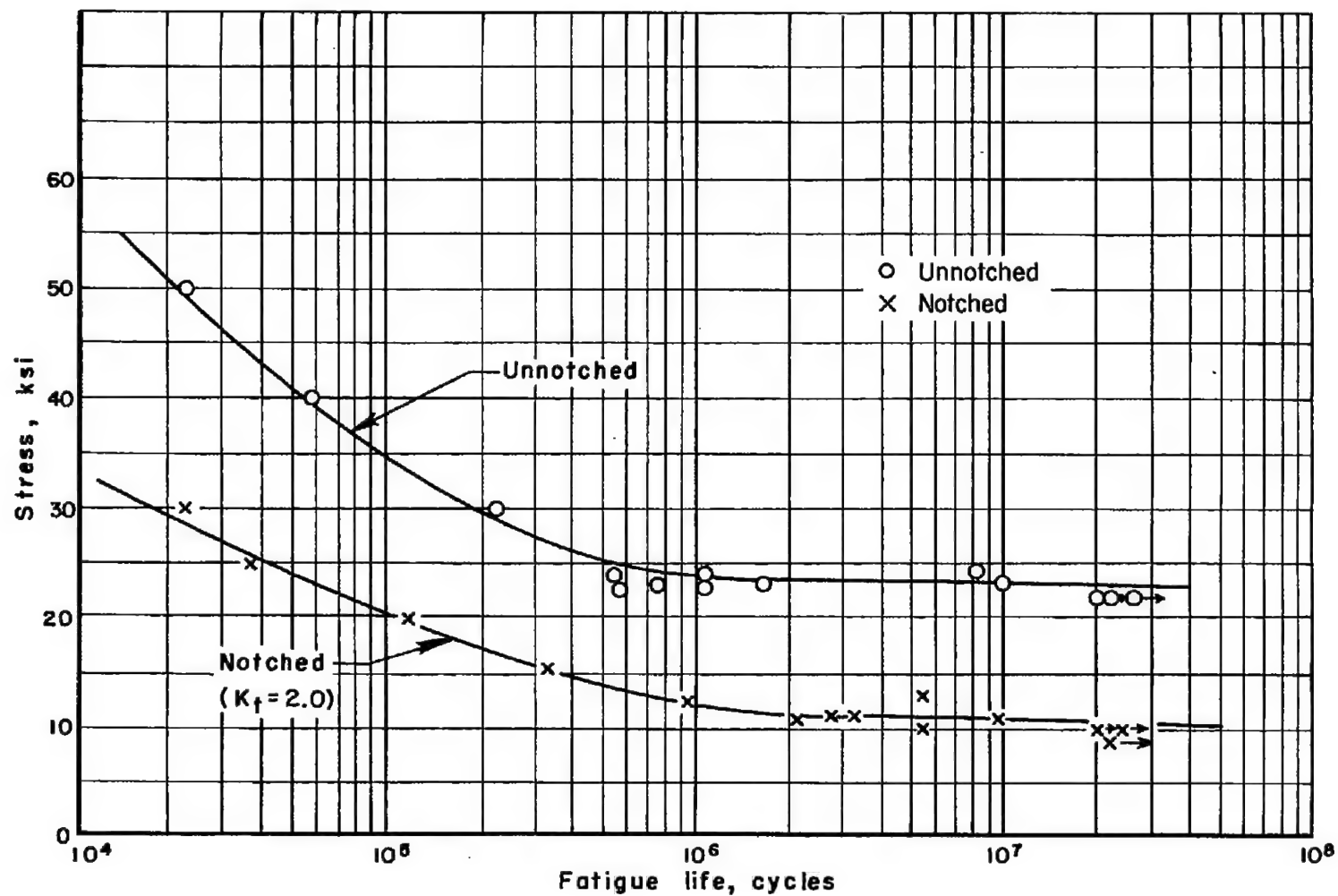


Figure 19.- Fatigue-test results on 1/2-inch-diameter specimens.

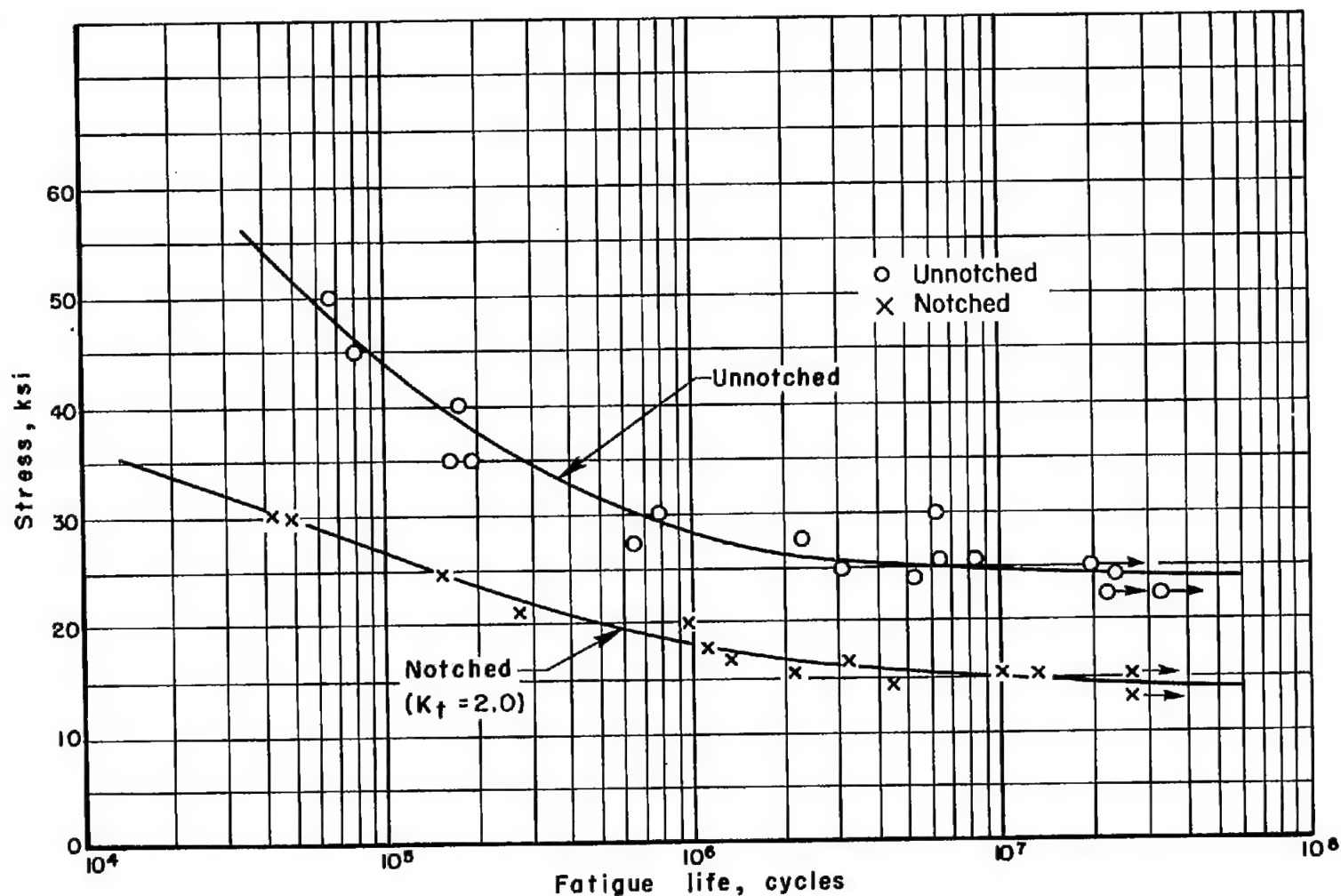


Figure 20.- Fatigue-test results on 1-inch-diameter specimens.

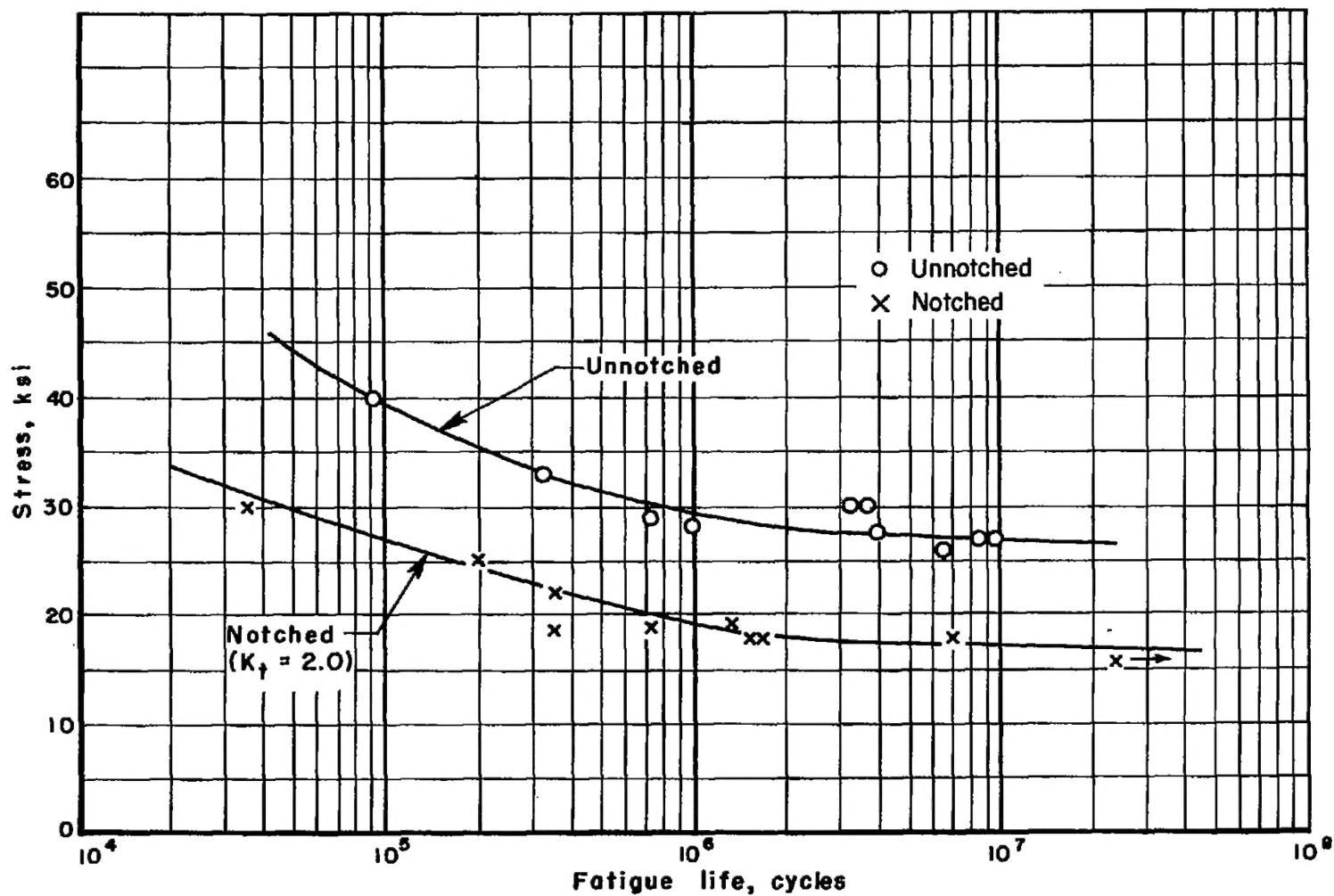


Figure 21.- Fatigue-test results on  $1\frac{3}{4}$ -inch-diameter specimens.

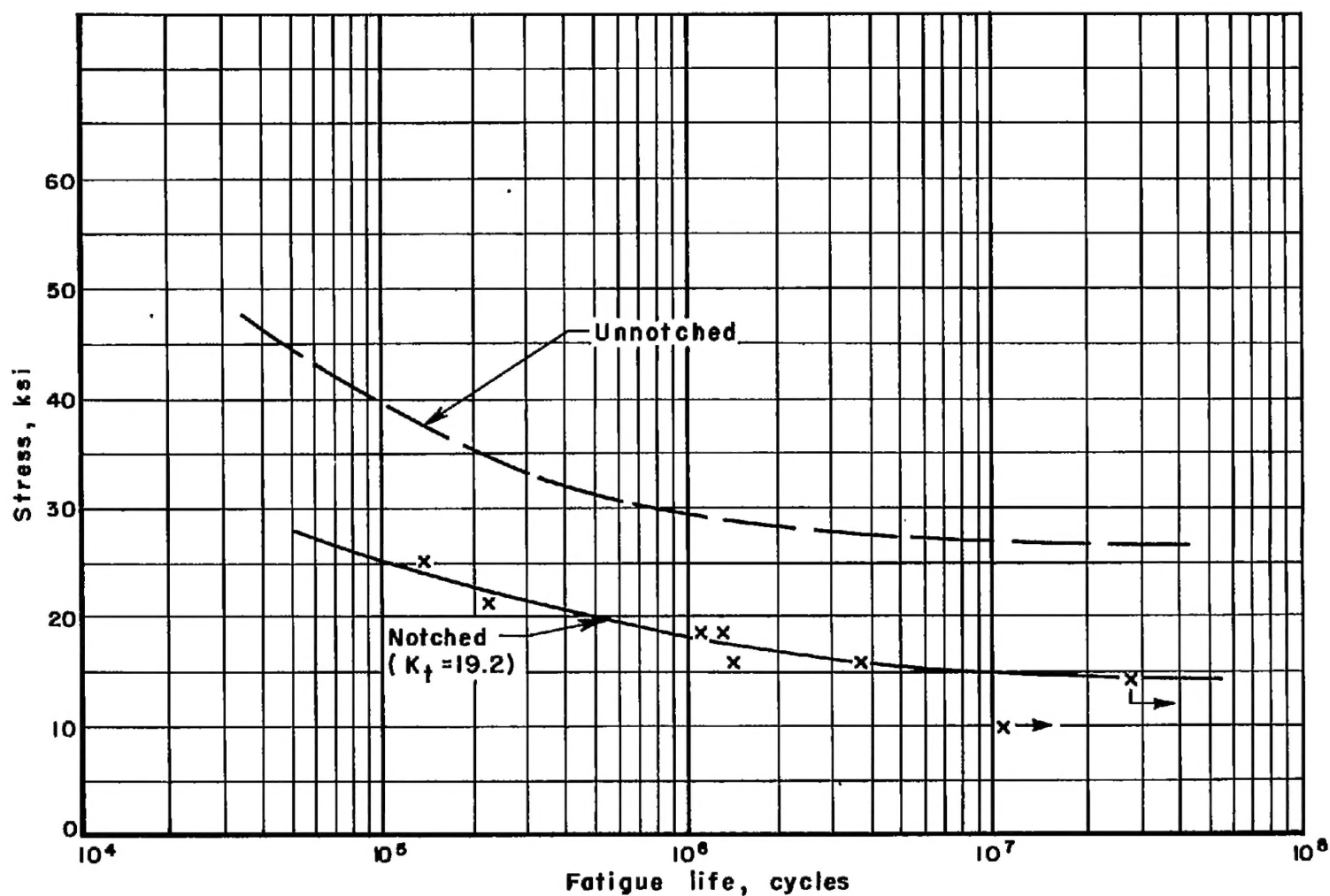


Figure 22.- Fatigue-test results on  $1\frac{3}{4}$ -inch, V-notch specimens.

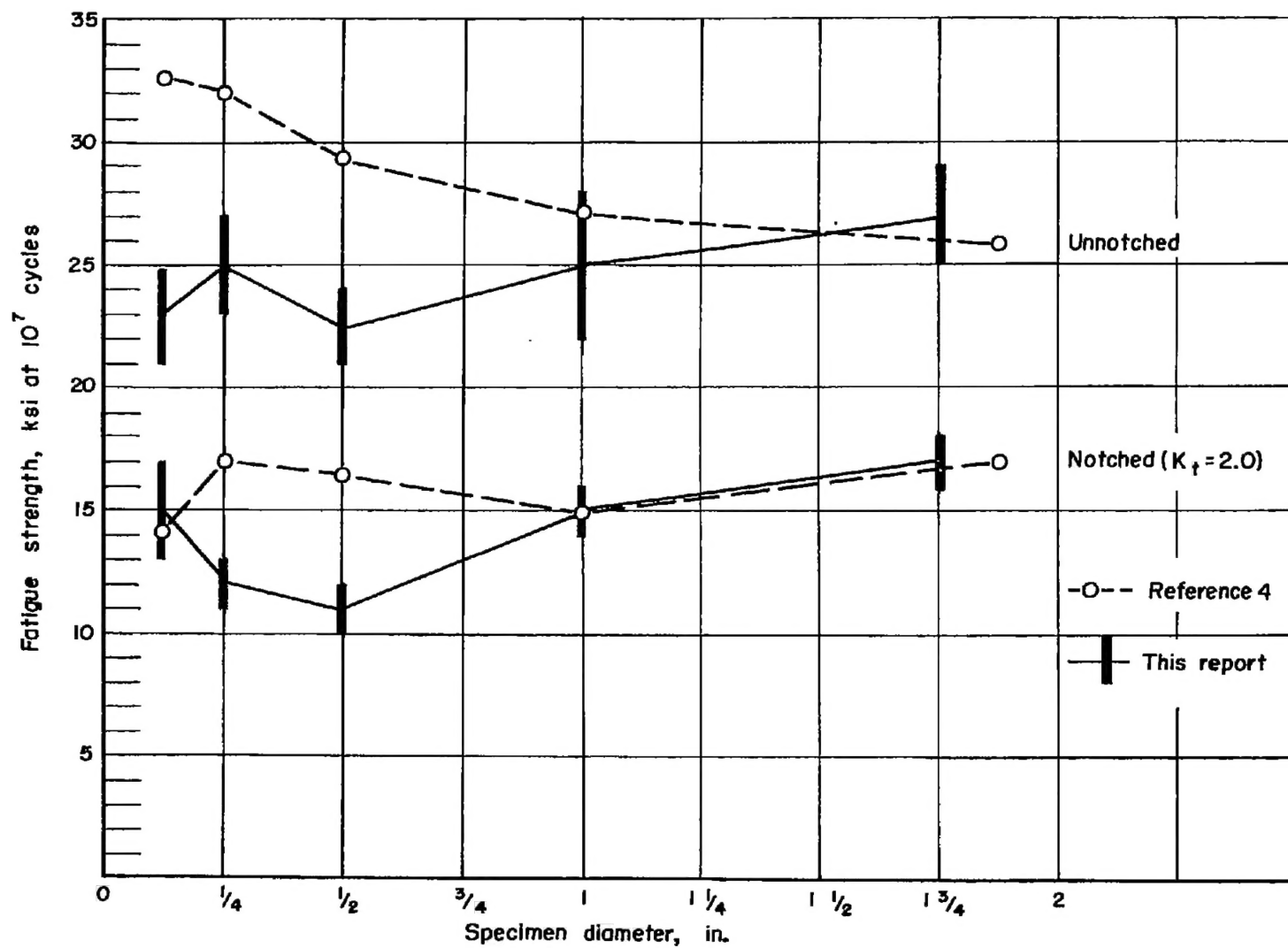


Figure 23.- Fatigue strength versus specimen diameter.

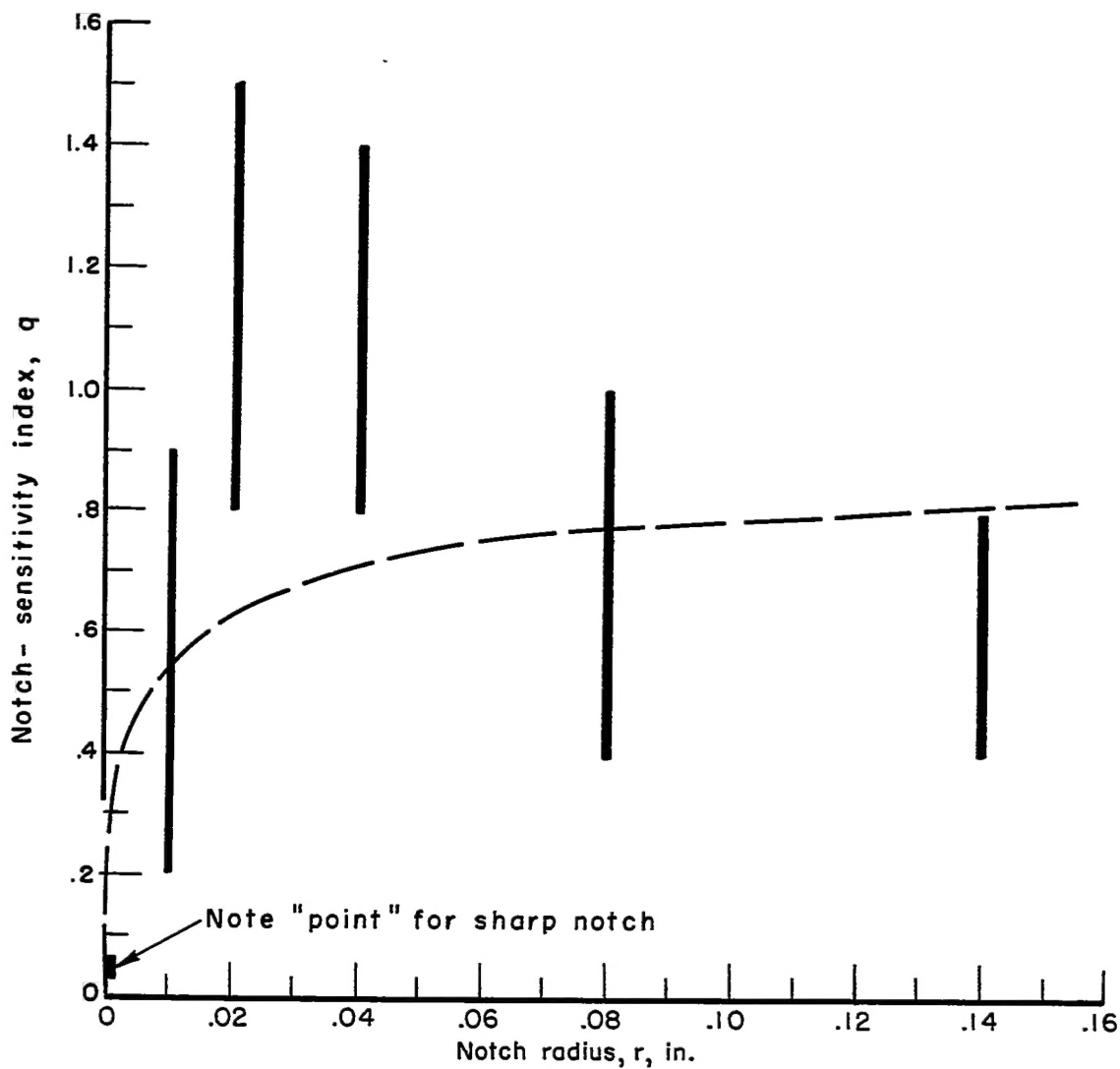


Figure 24.- Notch sensitivity versus notch radius. Vertical lines represent observed "points." Dashed line represents Neuber's theory with  $\rho' = 0.007$  in. (ref. 6).